FEM-SIMULATION OF TRANSVERSE DEFECT CLOSURE IN AUSTENITIC STAINLESS STEEL BY RADIAL SHEAR ROLLING

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Abstract

The process of closing defects in 12% Cr austenitic stainless steel by radial shear rolling on an RSP 10-30 mill was investigated. The advantage of radial shear rolling over other rolling methods is that it is an efficient way of achieving a high monotonic uniform deformation of the steel. The rolling sample was taken as an ingot of 12X13 steel with a diameter of 30 mm and a length of 150 mm. For mathematical research of the trough defects' behavior in the radial-slide rolling mill calculation model was carried out in the software package Deform-3D. In the ingot were simulated transverse defects of different diameters and depths with initial diameter d_0 of 5 mm and 2.5 mm and initial depth h_0 of 5 mm and 2.5 mm and one through. The simulation aim was to compress the ingot from a diameter of 30 mm to a diameter of 15 mm with the step of rolling by 1.5-2 mm. Based on FEM modeling the evolution of defects in various intermediate stages of radial-shear rolling has been analyzed in order to investigate the possibility of defect closing.

Keywords: Metallurgy, Stainless steel, FEM, radial shear rolling RSP, Casting defects

1. INTRODUCTION

This work is part of a series of studies on the obtaining of oxide-dispersed alloyed steel (ODS-steel) by casting methods. Therefore, 12% Cr steel was chosen for the work. This nickel-free stainless steel is a promising nuclear engineering material for the Gen-IV next generation reactors [1]. However, like all cast materials, this steel requires effective improvement of the cast structure, which may contain typical defects [2]. Also, most importantly, intensive mixing and refinement of alloying inclusions until a highly dispersed homogeneous system is achieved.

Forging is traditionally used for closing and welding defects in the cast structure of ingots. There is a whole line of theoretical and experimental research devoted to the intensification of the process of closing defects, represented by works like [3] and [4]. The use of other deformation methods for closing defects, such as rolling, is less popular, due to the higher level of tensile stresses that are harmful to closing defects.

One of the interesting and promising methods is Radial-Shear Rolling (RSR) process, invented by prof. C. Galkin [5-6]. 3-roll RSR provides an extremely high level of deformation (in this case, more than 30 mm/mm). The strain-stress state differs from conventional two-roll skew rolling for pipe piercing. RSR do not have a high level of tensile stresses in the central zone, and they are balanced by compressive ones. This fact, as well as a huge level of deformations, makes it possible to significantly change the sample structure to the UFG state, which was demonstrated in [7]. This type of rolling was used for rolling austenitic steel ingots in [8]. However, studies of defect closure by this method have not been carried out. The process is shown in **Figure 1.**

The strain-stress state is realized in the presence of a state of defect closure. Therefore, a study was made of the theoretical and experimental processes of closing defects by the method of radial shear rolling in an ingot.

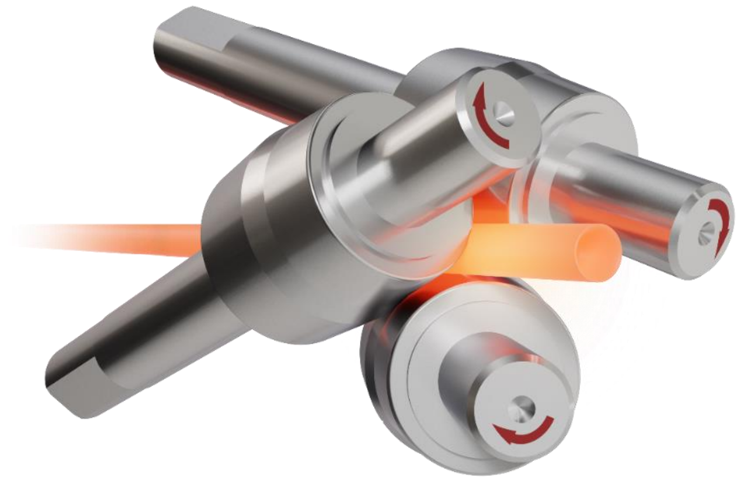

Figure 1 Radial-Shear Rolling

2. MATERIALS AND METHODS

The study of closure defects was carried out by two methods. The first one is the method of theoretical modeling of finite elements of rolling of parts with a number of holes representing defects. Such work is quite common, but mainly for forging. The theoretical process has not yet been investigated. The second one is checking the passage of real rolling by a real ingot with a built-in defect drilled before rolling. The dimensions of the parts and the dimensions of the holes representing defects are shown in **Figure 2**.

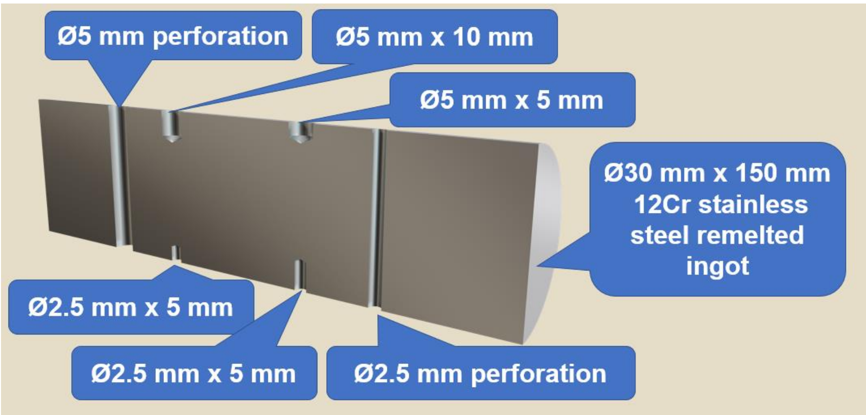

Figure 2 Dimensions and location of defects for simulation

For simulating the defects closure, a small ingot with a diameter of 30 mm and a length of 150 mm was cast from 12% Cr stainless steel. The ingot was obtained by induction melting and vacuum casting in accordance with the proposed technology for producing cast ODS steel and to provide a typical cast microstructure. The dimensions of the ingot are dictated by the operating range of the RSP 10/30 radial shear rolling mill, which makes it possible to roll this ingot with a total reduction of more than 50 % [7].

The rolling computer simulation was carried out in the DEFORM-3D software package (by SFTC) from 30 mm to 20 mm in 4 passes with a reduction of 2.5 mm per pass. The corresponding experimental material was selected from the DEFORM material library. Heating at 1,200 °C was in accordance with the conditions of the hot rolling process. 100,000 tetrahedral finite elements were used.

Verification was carried out on the RSP 10/30 mill in accordance with the simulation. The defective part of the ingot after rolling was cut on a QATM Brilliant-220 precision cutting machine into 50 sections of 1 mm each (with a cutting wheel thickness of 0.5 mm). Thus, 50 sections were obtained every 1.5 mm. The cut discs were numbered and scanned at 1,200 DPI and then imported into CAD Kompas-3D (ASKON) for vector graphics transformation and 3D reconstruction of defect cavities.

3. RESULTS AND DISCUSSION

Simulation results of this process previously had very good convergence [7]. However, in this case, the convergence took place only until the formation of closed cavities inside the workpiece from all sides due to a higher level of shear deformations in the peripheral parts of the workpiece and the difference in the directions of metal flow. This is very different from the well-known classical cases of simulating the closure of horizontal holes, simulating defects during upsetting by forging [4]. In this case, in contrast to ours, the defect simultaneously collapses along its entire length without the formation of cavities. The formation of several closed cavities causes problems in the calculation, after which the simulation loses convergence. However, there is a pattern of welding of the outer regions of the defect and stretching of the inner ones. The simulation results are shown in **Figure 3**.

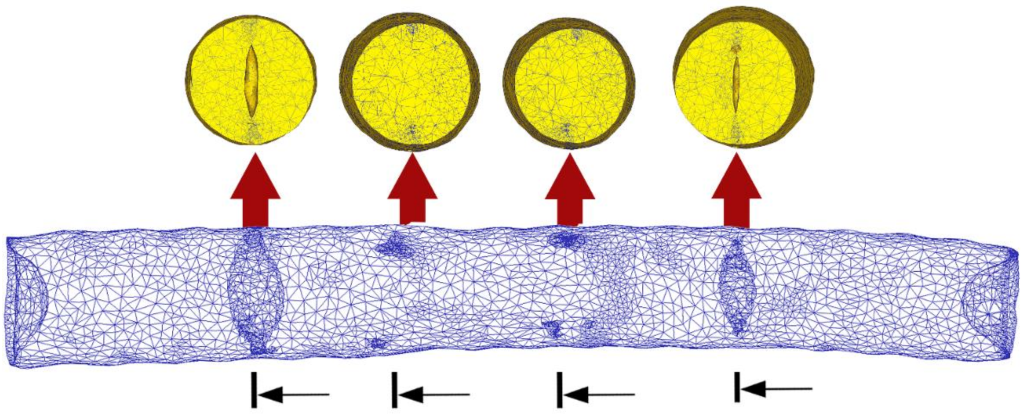

Figure 3 FEM-simulation of defect closure by Radial-Shear Rolling

Cross-sectional reconstruction of cavities of real defects after rolling is shown in **Figure 4**.

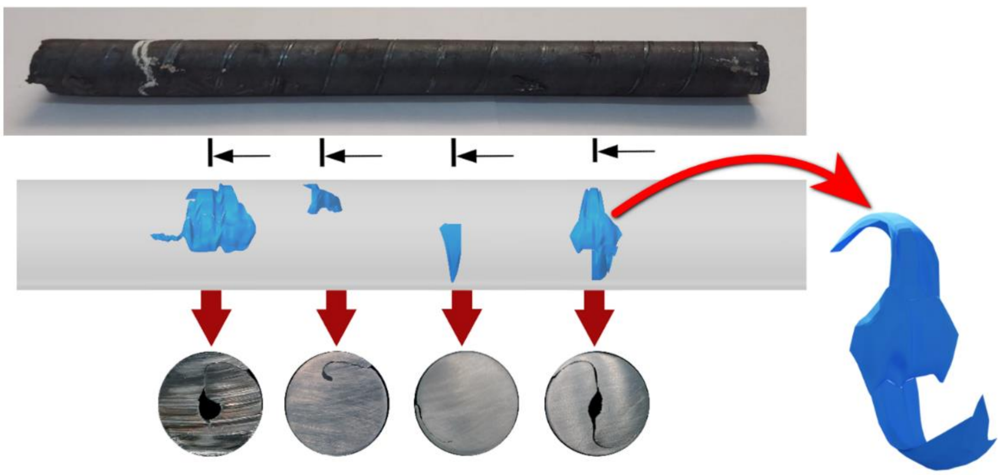

Figure 4 Reconstruction of defect evolution by experimental Radial-Shear Rolling

As can be seen from the results of experimental rolling, defects are not completely closed, especially through defects. The cross sections clearly show the difference in the directions of metal flow over the cross section.

Peripheral areas of defects are close to closing, and small non-through defects are completely welded. This makes it possible to predict the efficiency of the process in the presence of shallow surface defects, but it is very critical to use the method in the event of any discontinuities in the axial zone of the ingot. Apparently, the balance of compressive and tensile stresses in the center of the workpiece, in the case of a solid sample, is shifted towards compressive stresses and contributes to intense deformation of the entire section without destruction and with structure refinement, which is observed in various sources [6-8]. However, in the case of a non-continuous sample with cavities inside, the stress balance shifts towards tensile stresses and a cavity develops, but only in the axial region of the ingot. This hypothesis should be tested by a cycle of additional FEM simulations while eliminating problems with the calculation of the deformation of closed cavities.

4. CONCLUSION

Based on the presented results, we can postulate the following:

1) FEM simulation is the bad way for such complicated cases transverse defects studies. When the defect become to closed bubble shape, the simulation become to lose the convergence.
2) The experimental rolling show full closing all of the Ø 2.5 mm small defects excluding the perforation. All of the Ø 5 mm defects was not fully closed.
3) The periphery zone of defects had more nonhomogeneous deformation and has the compression along the radius. The central zone of defects had the homogeneous rod-axis directed deformation and the hole defects are getting longer regards the rod axis in central zone.
4) The 3 rolls radial-shear rolling are good for closing peripheral defects, but strongly not recommend for casting internal defect-containing ingot treatment.

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